Windmills

We Don't Create Energy, We Convert Energy!

Levels: Grades 4- 12

Content Areas:
Engineering; Physics, Energy

Lesson Time: 90 Minutes

Next Generation Science Standards:

Performance Expectations

3-5-ETS1, 4-PS3-4, MS-ETS1, MS-PS3-5, HS-ETS1, HS-PS3

Disciplinary Core Ideas

PS3.A: Definitions of Energy

PS3.B: Conservation of Energy and Energy Transfer

Crosscutting Concepts

Patterns

Cause and Effect

Energy and Matter

Structure and Function

Science and Engineer Practices

Developing and Using Models

Analyzing and Interpreting Data

Using Mathematics and Computational Thinking

Constructing Explanations and Designing Solutions

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Description

In this lesson, students will design, build, and test windmills made from various materials to generate mechanical energy. The windmills are a model of energy conversion from kinetic energy (wind) to mechanical energy (turning of the blades to power the generator) to electrical energy (induction of the wires and power output). Students will learn about of renewable energy and energy transfer by measuring volts, current, and power, as well as the engineering process, manipulating variables, and budgeting resources.

Outcomes

- Students will design, test, and revise a model of energy transfer.
- Students will measure/compute voltage, current, and power.
- Students will learn about renewable energy.
- Students will practice conserving resources and budgeting.

Guiding Question

How can we design windmills to efficiently transform wind to useable electricity, while also meeting design criteria?

Background Information

Electricity is transported energy through the motions of negatively charged atoms called electrons over distances, usually using wires. It's used to charge our cell phones, microwave food, and to light up a room. However, it's important to know that we don't create electrical energy. We convert electrical energy from other sources (e.g. wind, solar, geothermal, fossil fuels, and nuclear). This is known as the First Law of Thermodynamics. Most of the electricity we use right now is generated through turning pressurized steam turbines. The burning of nonrenewable fossil fuels is used to heat water into steam, which turns the turbines to generate electricity. During this process, carbon dioxide is released into the atmosphere. Carbon dioxide is a key greenhouse gas that contributes to climate change. Over the past decade, a shift from non-renewable to renewable energy (wind, solar, hydroelectric, biomass, and geothermal) has been contributing to powering our electrical needs. This shift from non-renewable energy to renewable energy is seen in domestic and international policies, U.S. tax credits and subsidies, growing consumer demand, and a growth in conversion technologies.

Wind energy is one of the most efficient ways of converting kinetic energy into electricity. Most windmills are often high up in the sky because of faster and more consistent wind, reaching a towering height of nearly 212 feet up. The blades of windmills are uneven to capture the wind and spin the turbine. While these blades only rotate at a speed of18 rotations per minute, each blade can be as long as the length of a football field or 130 feet. Windmill blades are attached to the hub and the hub is attached to the nacelle. In the nacelle, a rotor shaft spins as the blades are spinning. The rotor shaft spins a series of gears at about 1800 rotations per minute. These rotations help power the generator and the generator converts the kinetic energy of wind into electrical energy that flows into power grids for homes, towns, and cities. However, a single windmill costs nearly $4 million dollars to produce.

Materials

Windmill Tower:

- 1 - 10 ft 1" Diameter PVC Pipe
- 1 - Ratcheting PVC Cutter
- 5 - PVC 90 Degree Elbows
- 3 - PVC Tee Socket
- 1 - PVC Coupler
- 1 - KidWind Wind Turbine Generator with Wires*
- Ductape

Additional Materials:

- 1 - Large Box Fan
- 1 - Digital Multimeter
- 2 - Alligator Clips
- 1/4 Dowels, cut into 5 in pieces
- KidWind Wind Turbine Hub*
- Cardboard
- Paperboard
- Cardstock
- PowerPoint Slides (smile.oregonstate.edu)
- Student Handout (smile.oregonstate.edu)

**Purchase on www.vernier.com, page 5 for links*

Each Kit per Group Includes:

- 1 Hub
- 2 Dowels
- 1 Pair of Scissors
- 1 Roll of Tape
- 1 Marker or Pencil
- 2 Minutes of Testing Time
- $4 Million Dollar Budget

Assembling the Tower

Prior to Assembling:

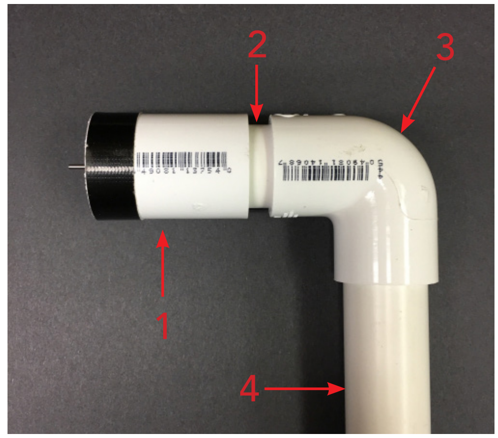
1. Cut the 10 ft PVC pipe using a Racheting PVC cutter into:
   - 1 - 1.5 to 2.5 ft piece
   - 1 - 2.5 inch piece
   - 6 - 5.5 inch pieces

2. Drill a hole in the middle of the long horizontal side of a Tee Socket. This is where the two wires will be threaded through tconnect to the multimeter.

3. Cut the 1/4" inch dowel into 5" pieces. Cut enough for every group to have 2 dowels, and extras for students to "purchase".

Assembling Tower Top:

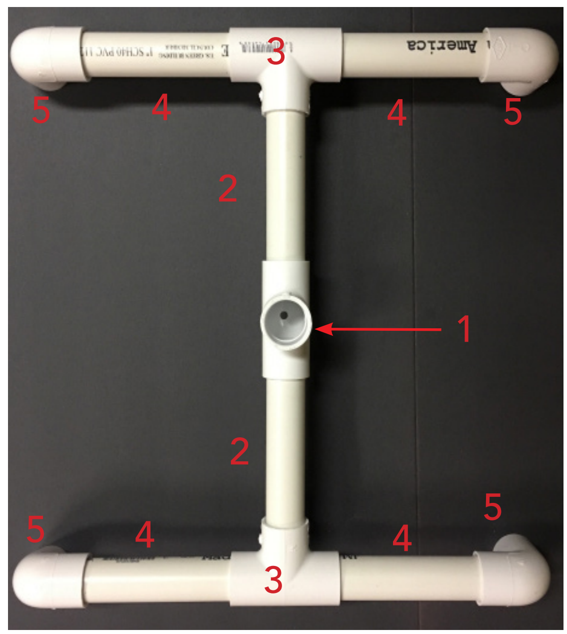
1. Attach Wind Turbine Generator into the coupler. Secure with ductape inside.
2. Secure coupler to the 2.5 in. PVC pipe.
3. Attach a 90 Degree Elbow to the PVC pipe.
4. Attach the 1.5-2.5 ft PVC pipe to the 90 Degree Elbow.



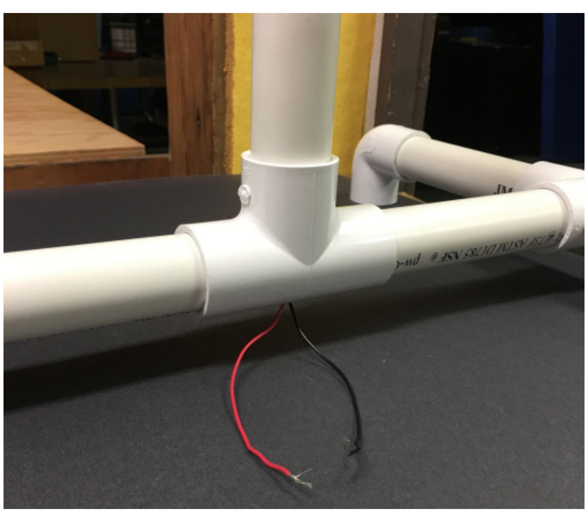
**The two wires shoud hang 5 or more inches out of the PVC pipe. If not, cut your PVC pipe shorter.

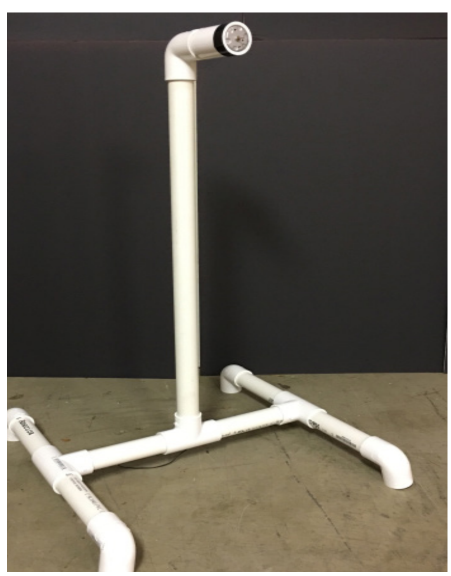
Assembling Tower Base:

1. Set PVC Tee Socket with a drilled hole in the center.
2. Connect 5.5" PVC pipes to both ends.
3. Connect PVC Tee Sockets to both ends of PVC pipes.
4. Connect 5.5" PVC pipes to both ends of the sockets.
5. Attach 90 Degree Elbows to all ends of PVC pipes. Rotate elbows to stand on table.



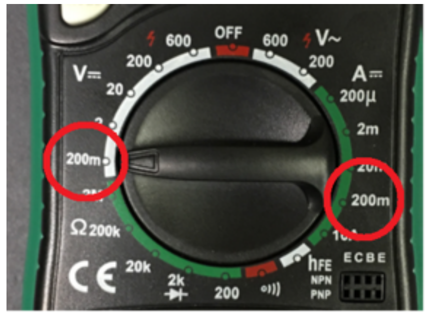
Attach the top to the base. Thread the two wires thru the drilled hole on the PVC Tee Socket at the base.

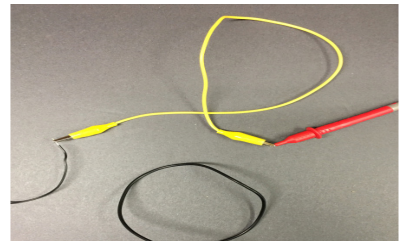




Your tower should resemble these photos to the left.

Connecting and Reading Multimeter





1. Plug the red wire to the left most input socket labeled "10ADC", and the black wire to the right most input socket labeled "VΩmA"

2. Attach alligator clips to the ends wires from the tower. Then clip the ends of the alligator clip to the multimeter.

3. Turn the multimeter to the left to 200m volts (V). This will show the volts in millivolts (mV) being produced by the windmill on the LCD display.

4. Turn the multimeter to the right to 200m Amps displayed in the A section of the dial. This will show the current in milliamps (mI) that are being produced by the windmill on the LCD display.

5. Note, you multiply the displayed millivolts by the displayed milliamps to get the power output of the windmill in milliwatts (mW). If these units were converted to the SI of Volts (V) of Amps/Current (I), you need to multiply them by .0001 because 1 millivolt or milliamp or milliwatt equals 0.001 (or 10-3) volts or amps or watts.

Designing Windmills

Guiding Question: How can we design windmills to efficiently transform wind to useable electricity, while also meeting design criteria?

Design Criteria: With a budget of $4 million, design a windmill that maximizes energy output while conserving resources and money that also looks aesthetically pleasing.

General Procedure

1. Introduction slides and video. (5 -10 Minutes).
    a. The slides are useful in showing the conversion of energy from Wind to Electricity, and can be found on the SMILE web page.
    b. The video is useful in showing what windmills are, how big they are, and how variable their designs can be.

2. Pass out student handout and go over what they will be recording. (5-10min)
    a. Note that they will be making a resign, seeing how it preforms, recording data and making changes.
    b. Ask students what variables they will be keeping the same – independent variables and

controlled variables (e.g. wind speed, distance from fan, height, testing time, etc.) and which ones they will change (e.g. blade length, blade materials, blade angle, number of blades, etc.) as they go from one design to the next. Be sure to let the students know the goal is to make the best design, so it may be hard to tell the impact of each change if they are changing more than one variable at a time.

c. Let the students know that they have to justify what changes they are making as they move from one design to the next.

d. Let students know they will have to decide on blade charecteristics

- Blade material
- Blade length, width, and angle
- Number of blades
- Spacing between blades

3. Separate students into groups of 3 - 5, hand out kits, create a team name, and assign roles. Note, this roles can change throughout the activity and be more or less complex depending on your students' needs, interests, or wants.

a. Speaker/Big ideas person.

- The speaker and BI person pulls the group (occasionally) back to the scientific purpose of the activity (often a group will get too wrapped up in the rote execution of the directions), as well as shares out during the presentation.

b. Purchaser/Questioner.

- This person asks probing questions during the activity and goes to purchase needed supplies. These folks listen for questions posed by other group members and then re-voice the questions to make sure that the whole group takes a moment to hear and entertain questions from everyone.

c. Recorder/Skeptic.

- This person tries to strengthen the group's work by probing for weaknesses in the developing explanation or model, while also recording information about the design (e.g. mV, mil, and aesthetics).

d. Accountant/Progress monitor.

- This person ask others to periodically take the measure of the group's progress, and keeps track of money spent.

4. Allow students to brainstorm a design, draw it out, and to budget materials. Accountant keeps track of money. (10 Minutes)

a. Purchaser buys necessary materials. (5 minutes)

b. Assemble windmill. (10 Minutes)

- This can be done before the lesson.

- One windmill can be setup in the front of the room, and then each team can come up and test their design one at a time.

5. Testing time, 2 minutes per group - unless the team buys extra time. Recorder writes energy output voltage on board. (20 minutes)

a. Output is calculated: Volts (mV) x Amps (I) = Power (Watts)

b. Encourage students to buy testing time! Most groups underestimate how important testing their build is.

c. The student handout is provided for 3 trials per design and has room for 3 designs, as well as space for students to justify their changes in the design and to keep track of costs.

6. Have groups return to tables to redesign or adjust windmill to maximize energy output.

7. When testing is completed, prepare a 2 minute elevator speech about their engineering design process and findings. (10 minutes)

a. Before the whole class share out, you may also want each group to share their design to get feedback from other groups. This could be done using stick notes in a gallery walk or in a more formal check-in and share out.

8. Presentation, final test, and then have the rest of the class vote on aesthetics (1 to 5, 1 being unappealing and 5 being aesthetically pleasing) (20 minutes)

a. You may want to give extra time to students to decorate their windmill blades.

9. Calculate final scores by: ((Avg. Power of best design)/(Amount of money used))+ Aesthetics Score = Final

Money Values:

Dowels	1 million/each
Cardboard	0.5 million/sheet
Paperboard	1 million/sheet
Cardstock	1.5 million/sheet
Testing Time	0.5 million/sheet

Example Score Table:

Team Name	mV	I	Power (mW) = (mV*mI)	Money Used (mil)	Aesthetics Score (1-5)	Final Score
Ducks				3.5	4	((mV*I)/3.5)+4=
Beavers				2	5	((mV*I)/2)+5=

Experiment Questions

- Where is the energy needed to spin the windmill coming from and what kind of energy is it converted into when it spins? How does that energy get converted to electrical energy?
- What claim can you make between the power output and the variables you changed? Cite evidence from you design process to support your claim.
- Calculate your team's power to cost ratio by dividing power (milliwatts) by cost (mil) to get your power to cost ratio (milliwatts/mil) for each design. Which design had the highest power to cost ratio? Is that the design your team feels is the best? Why or why not?

• In order to make your team's best performing design inviting to investors, how do you plan on aesthetically embellishing it so that communities will be willing to have a wind farm near their home? (Scored on a 1-5 scale; make your reasoning convincing!)

Teacher Hints and Scaling

The Windmill that "wobbles": The wobble looks like a clunky rotation that is not uniform in speed. If the windmill is wobbling, then prompts students to look for blades are not uniform in length, weight, material or angle.

The Windmill that won't spin: The windmill that won't spin may have blades that are too heavy or blades that are at angles that do not complement each other, therefore canceling out propulsion because the wind each blade is catching is going in opposite directions. This effect is similar to waves that cause interference as opposed to complementing each other. Lastly, sometimes the energy needed to get the blades going is more than the wind available. If that is the case, give the windmill a gentle spin to get it going.

Blade Angle: The angle of the blades relative to the direction of the wind matters. If the angle is to sharp then the blades may not be able to catch wind, if they are to flat then the same thing may occur, and if the blades are at opposing angles then the windmill may not move or it may have an awkward rotation.

Where to tape? Always put tape on the side of the blade that is not facing the wind. This allows for more surface are to "catch" the wind.

What materials work best?

Cardstock, cereal boxes, and any material that holds it shape, is light, and can bend a little. While this activity does state you can use cardboard, corrugated cardboard may be too heavy for some designs.

Extension Activities

Independent and Dependent Variables

Students may want to change more than one variable per design. If they choose to do that, ask them how they will determine which change is effecting the power output. This may point them in the right direction of only changing one variable a time for each design phase. In this experiment, the control, or independent, variable is the speed of the box fan you are using to blow on the windmill. The dependent variables, which the students are changing and measuring, are the number of blades, size of blades, angles of blades, and the power being produced by the windmill. For younger students, going over independent and dependent variables can be incredibly helpful to ensuring they systematically change and test their designs.

International System of Units (SI)

SI units are commonly used in science and engineering to relate findings, measurements, and data to other research teams. Students may not be aware of the different types of units used to measure scientific process, such as meter for distance – but then we have millimeter, centimeter, kilometer, etc. The same goes for litters (volume), or grams (weight). This conversation can be interesting if your U.S. born students have not considered why some countries use the metric system, while the U.S. uses U.S. customary units (feet, ounce, and cups). It is interesting that only Burma, Liberia, and the U.S. do not use the SI system, or Metric system. Furthermore, if you introduce your students to the metric system then you can go over base 100 (e.g. units are classified from 1, 10, 100, 1000, etc.).

Discussing "Line Loss"

Line loss is the phenomena that occurs when electricity is transferred over long distances and loses some energy because the electrical energy generated by the windmill turbine has to transport that energy across power lines (low and high voltage) to local energy grids to your home and then to your electrical wires and outlets. As that energy is transported, energy is converted to heat and electromagnetic energy resulting in energy loss. To compute an indicator of line loss you can compute the resistance of the wires used in the windmill, this is by Voltage = Current x Resistance. Therefore, as students already recorded Voltage and Current for their design, they just need to divide Voltage by their Current to get their models Resistance. Resistance is an indicator of how efficiently a wire can conduct and transport electrical energy.

Resources on Line Loss

- Video: http://insideenergy.org/2015/11/06/lost-in-transmission-how-much-electricity-disappears-between-a-power-plant-and-your-plug/

- In the U.S., generating electricity loses 22 quadrillion Btu from coal, natural gas, nuclear and petroleum power plants as of 2013 – that is more than the gasoline used in the U.S. each year.

- Then moving electricity from plants to homes and businesses on the transmission and distribution grid, we lose 69 trillion Btu in 2013 – that's about how much energy Americans use drying our clothes every year.

Wind Power in Oregon (or your state)

OR is the second largest of wind power producing state. In 2016, 12.6% of the power used in OR was from wind. Previously in 2012, OR produced 4,289 megawatts and in comparison 1 megawatt is enough to power 1,000 homes. To grow wind power and renewable energy in OR, the state senate passed SB 838 which stipulates that all energy in OR must be 25% renewable by 2025, and 50% by 2040. This means that wind power and other renewable sources of energy will grow! The context of OR supporting wind power can give this activity real world meaning. This information might be helpful in creating by-in from your students to get them excited for learning about windmills, as well as teaching the nature of science and to provide an authentic science experience.